LTR-SEE-I-10-22 NP-Attachment

Response to NRC Request for Additional Information on WCAP-17057-P, Revision 0, "GSI-191 Fuel Assembly Test Report for PWROG"

February 2010

Westinghouse Electric Company LLC
P.O. Box 355
Pittsburgh, PA 15230-0355

Table of Contents

1.0 RAI Responses

This document provides responses to requests for additional information [1] related to WCAP-17057-P, Revision 0.

1.1 RAI #1

1.1.1 Question

Page 7-2, Table 7-2 lists a maximum microporous insulation debris load of 3.2 lbm while the maximum quantity tested was 1.47 lbm: Please discuss why a 2.2x factor above the tested amount is acceptable for microporous insulation.

1.1.2 Response

Upon issuance of this RAI, Westinghouse and AREVA test results presented in [2] and [3] were evaluated. Additionally, the PWROG conducted additional fuel assembly tests [4]. It was concluded microporous insulation behaves like a particulate and should be characterized as such. Therefore, plants with microporous insulation are bounded by the results of tests conducted with silicon carbide as the particulate source. This conclusion is supported by the discussions in the following sections.

1.1.2.1 Description of Microtherm used in FA Testing

Microporous insulation does have a fibrous content which is removed when the microporous insulation passes through the sump screen. The preparation of the microporous material for fuel assembly tests simulated this process. The microporous insulation Microtherm was obtained from Microtherm, Inc. The material was supplied in a pulverized form. It was passed through a #7 sieve with a hole size of 0.11". The sieving is necessary to obtain test material that is representative of Microtherm that would pass through the sump screen. Then the material was characterized by scanning electron microscopy. An individual particle of microporous silica is shown in Figure 1-1. A lower magnification image showing multiple Microtherm particles is displayed in Figure 1-2. The processed Microtherm material appeared to be almost completely devoid of fibers suggesting that they had been removed by the screening process and is essentially a particulate.

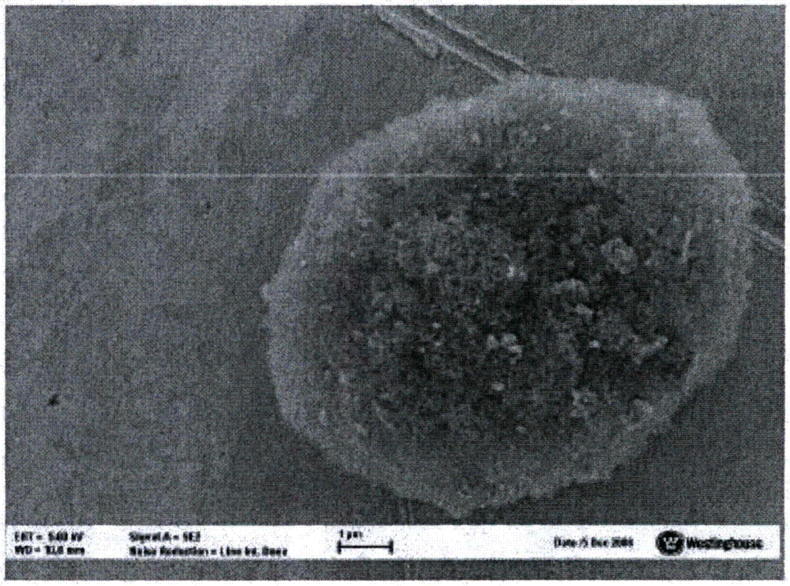

Figure 1-1: Microtherm – Individual Particle

Figure 1-2: Microtherm – Multiple Particles

1.1.2.2 Comparison of Hot Leg Break Data for Microtherm

Westinghouse and AREVA conducted tests with similar debris loads at hot-leg break conditions for the original submittals [2 & 3]. A comparison of the total fuel assembly pressure drop with fiber addition for the hot-leg break tests for three tests that have similar conditions (CIB08, FG-FPC-W-2 and CM-FPC-W-3) is shown in Table 1-1. Based on a comparison of these data, test results from the Westinghouse fuel assembly reasonably represent test results that would be attained from the AREVA fuel assembly (and vice versa). Therefore, it was initially concluded that the RAI responses that require testing can be answered with tests run by either Westinghouse or AREVA using the same apparatuses that were used to provide the original test results. Additionally, this data can be used to support the following conclusion.

The results of two tests from [3] are used to evaluate how Microtherm behaves at hot-leg break conditions - FG-FPC-W-2 and FG-FPMC-W-6. FG-FPC-W-2 was conducted with silicon carbide as the only particulate debris. FG-FPMC-W-6 contained both silicon carbide and Microtherm as the particulate debris. A summary of the test parameters are provided in Table 1-2. The pressure drop with each fiber addition before chemical precipitate addition is shown in Figure 1-3 (note that only half of the Microtherm had been added). This comparison clearly shows that the additions of fiber and chemical have the same effect on the dP across the entire fuel assembly.

Table 1-1: [ ]a,c

a,c

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 1-2: [ ]a,c

a.c

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

a,c

Figure 1-3 [ ]^{a,c}

1.1.2.3 Comparison of Cold Leg Break Data for Microtherm

Additional testing was conducted to evaluate how Microtherm behaves at cold-leg break conditions – CIB26 and CIB40 [4]. Both of these tests included Microtherm in the debris mix. A summary of the test parameters and results are provided in Table 1-3. Tests CIB29 through CIB33 [4] did not include Microtherm in the debris mix, but they are also included and will be used in the following discussion.

In order to provide a meaningful comparison of these tests, the particle size of silicon carbide and Microtherm requires consideration. Microtherm has approximately the same particle size as silicon carbide; however, the density of Microtherm is much less than that of silicon carbide. The density of Microtherm ($\rho_{Microtherm}$) is 2,199 g/ft^3 [4, Section 3.6] and silicon carbide (ρ_{SiC}) is 28,260 g/ft^3 [4, Section 3.6]. A comparison of a test with silicon carbide to a test with Microtherm should be based on the number of particles tested, because the pressure drop is due, in part, to how the particles fill the interstitial gaps in the fiber bed. If the mass is used, then the number of particles will be different which means that a different number of gaps will be filled. Since both particulates have the same particle size, the volume of the particle will cancel out and the determination of the number of particles reduces to a simple density ratio. The density ratio, $\rho_{SiC} / \rho_{Microtherm}$, is equal to 12.9. Therefore, in order to test the same amount of particles, the mass of silicon carbide would need to be 12.9 times greater than the mass of Microtherm.

The amount of silicon carbide in CIB30 is 9 times greater than the amount of Microtherm used in CIB26. Therefore, these tests will have a similar number of particles and the results can be meaningfully compared. CIB26 was conducted with Microtherm as the sole source of particulate and CIB30 was conducted with silicon carbide as the sole source of particulate. A particulate-to-fiber (p:f) ratio of [ ]^{a,c} was used because Microtherm is not as dense as silicon carbide. Therefore, less particulate is needed to fill interstitial gaps. This test showed that even at a fiber load of 30g, which is more fiber than the cold-leg fiber limit, the pressure drop due to debris is less than the maximum of [ ]^{a,c} A comparison of CIB26 to CIB30 and the effect on head loss with each fiber addition is provided in Figure 1-4. It is clear fiber has a smaller effect on the head loss in the test with Microtherm. Therefore, Microtherm can be classified as a particulate.

CIB40 was conducted with both Microtherm and SiC to see if there was an effect due to the combination of particle sources. Accounting for the density difference between SiC and Microtherm, the p:f ratio in Test CIB40 is approximately:

( )^{a,c}

The highest p:f ratio of the cold-leg break tests with SiC only is [ ]^{a,c} However, the results of Test CIB40 continue the pressure drop trend of Tests CIB29 through CIB33. That is, the maximum dP was established at a p:f ratio of [ ]^{a,c} As the p:f ratio increases beyond the limiting condition of [ ]^{a,c}, the pressure drop decreases. Overall, CIB40 trended with the other cold-leg break tests further illustrating Microtherm is simply a particulate.

Table 1-3: [ ]^{a,c}

a,c

a,c

Figure 1-4: [ ]a,c

1.2 RAI #2

1.2.1 Question

WCAP-16793-NP, Table 10-1 on page 10-3 lists acceptable fiber debris loads for Westinghouse-designed fuel assemblies that are significantly greater than that included in the bulk of Westinghouse tests (Reference: WCAP-17057-P, Table 3-3). Only two tests (CIB08 and CIB10) were performed with fiber debris loads steadily increased to 200 grams. Several tests (CIB01 through CIB04) conducted with lower quantities of particulate appeared to trend toward exceeding the allowable head loss with significantly less fiber than the suggested acceptance criterion of 200 gram per fuel assembly. Page 5-3, Figure 5-1 graphs the pressure drop versus fiber debris loads for the 10 tests for flow introduced from the bottom of the core. Review of the test data shows that increasing fiber loading results in increased head loss. Since the objective of the test program is to determine a bounding amount of debris for a large set of plants, the tests should be conducted to determine the bounding amount of fibrous debris considering the possible range of other debris types and quantities. Please provide information that justifies that the testing has shown that the stated 200 gram fiber limit is valid under the other debris loading scenarios allowed by the acceptance criteria stated in the report. Include justification that the testing bounds conditions for lower flow rates, microporous debris loading, and varied particulate loading.

1.2.2 Response

The test matrix defined on Table 3-3 of [2] and the test results provided in Section 5 of [2] were all performed at particulate-to-fiber (p:f) ratios in the range of approximately [ ]^{a,c}, with the majority of tests conducted at [ ]^{a,c} In order to address the questions posed in the RAI, additional testing was performed for [ ]^{a,c} for both the hot- and cold-leg break scenarios. This additional testing was conducted at both the Westinghouse facility for Westinghouse fuel and at CDI for AREVA fuel. As appropriate, the results from either facility will be used to support fuel currently manufactured by either vendor.

As a result of the additional testing, [ ]^{a,c} The new acceptance criterion is discussed in the following sections. Plants must meet both criteria in order to demonstrate the fuel assembly testing is applicable.

1.2.2.1 [ ]^{a,c}

[

]^{a,c}

[

]^{a,c}

[

][a,c]

[a,c]

1.2.2.2 [ ][a,c]

[a,c]

a,c

Figure 1-5: [ ]a,c

1.3 RAI #3

1.3.1 Question

Review of the test data showed that the fuel assembly head loss is sensitive to the amount of particulate debris added to the test. The data indicates that lower particulate loads result in higher head loss. Please provide an evaluation of how fuel assembly head loss is affected by the amount of particulate debris. Because the fuel assembly test program is designed to provide bounding amounts of debris for a large set of plants, the test series should be conducted to demonstrate the bounding amount of debris, i.e., the amount of particulate debris that results in the highest head loss may not occur at maximum particulate debris loading. When this amount is determined, it should be evaluated to determine which plants are enveloped within the limiting amount. Note that the bounding amount of debris may change for various conditions (e.g. cold leg vs. hot leg flow, alternate debris loads such as calcium silicate and microporous insulation, varying fibrous loads, etc.)

1.3.2 Response

The test matrix defined on Table 3-3 of [2] and the test results provided in Section 5 of [2] were all performed at particulate-to-fiber (p:f) ratios in the range of approximately [ ]^{a,c}, with the majority of tests conducted at [ ]^{a,c} In order to address the questions posed in the RAI, additional testing was performed for [ ]^{a,c} for both the hot- and cold-leg break scenarios. This additional testing was done for both the Westinghouse facility for the Westinghouse fuel and at CDI for the AREVA fuel. As appropriate, the results from either facility will be used to support fuel currently manufactured by either vendor.

The response to this question includes a discussion of the additional test data, which results in new acceptance criteria for debris. The testing process is summarized in Section 1.3.2.1. The additional cold- and hot-leg break data is discussed in Sections 1.3.2.2 & 1.3.2.3, respectively.

1.3.2.1 Testing Overview

The FA testing program undertaken by the PWROG was designed to provide reasonable assurance that sufficient flow will reach the core to remove core decay heat. To that end, it must be demonstrated that the head available to drive flow into the core is greater than the head loss (also referred to as pressure drop) across the core due to possible debris buildup. The following relationship must be true to ensure sufficient flow is available:

$$dP_{available} > dP_{debris}$$

The available driving head ($dP_{available}$) is a plant-specific value. The PWROG is providing a tool (called the Margin Calculator) for utilities to determine this value. The details of the Margin Calculator can be found in [5]. The pressure drop due to debris (dP_{debris}) is determined by the fuel assembly (FA) test program.

The test plan and test facility are described in detail in [2]. A high-level summary is provided here:

1. The test facility is a closed loop system that continually recirculates fluid and debris through a single test fuel assembly.

2. The test chamber is formed by Plexiglas walls that are sized to match the fuel assembly pitch. The distance from the end of the test fuel assembly to the chamber walls is half of the distance between adjacent fuel assemblies.
3. The flow entering the bottom of the fuel assembly is uniform and constant.
4. All debris is available to form debris beds at either the bottom nozzle or at the intermediate spacer grids.

All of these design features contribute to the promotion of debris capture in the test loop and provide a conservative representation of the debris capture in an actual core.

1.3.2.2 Cold-Leg Break

1.3.2.2.1 Additional Cold-Leg Break Test Data

The original cold-leg data set did not contain information about low particulate debris loads. Therefore, a new series of tests were conducted in order to determine the effect of low particulate on cold-leg break conditions. Initial scoping tests (not reported here, but included in [4]) were conducted to determine the effect of particulate on head loss. [ ]^{a,c} They further indicated that fiber loads of [ ]^{a,c} provide reasonable assurance that flow would not be compromised following a cold-leg break. In order to prove plants with [ ]^{a,c} would be able to maintain LTCC, a series of tests were conducted at varying particulate to fiber ratios. This analysis was done to show that even at the limiting p:f ratio, [ ]^{a,c} would not impede LTCC. These tests show that [ ]^{a,c}

The test parameters used to define a new cold-leg break acceptance criteria are provided in Table 1-4. The limiting cold-leg break p:f ratio was determined by Westinghouse to be [ ]^{a,c}

[ ]^{a,c}

1.3.2.2.2 Cold-Leg Break Conservatism

The conservatisms in the acceptance criterion for the cold-leg breaks include:

1. The PWROG FA test program conservatively used a constant [ ]^{a,c} as the flow rate for the cold-leg break evaluations. In the event of a cold-leg break, the actual core flow rate is defined by the initial core power and the core decay heat. At the time of sump switchover (earliest time that debris can reach the core), the flow rate will be highest because the core decay heat is highest. Over time, the core decay heat decreases as does the core boiloff rate. The flow rate decrease results in a decreased pressure drop through a debris bed that has formed. It also reduces the velocity in the reactor vessel lower plenum and decreases the ability of debris to be lifted to the core inlet. Maintaining a constant, high flow rate ensures that all debris that might reach the reactor vessel over 30 days is introduced to the core and ensures the least porous debris bed. Therefore, maintaining a constant flow in the tests results in a conservatively high head loss.
2. A flow rate of [ ]^{a,c} corresponds to the highest expected core boiloff rate at 20 minutes after the LOCA. A sump switchover time of 20 minutes is conservatively determined by considering no

failures of the ECCS system and minimum liquid volumes in the RWST. At the minimum assured ECCS flow rate, this time is more on the order of an hour or more. At an hour after the event, the decay heat has decreased such that the core boiloff rate is approximately 2/3 of the boiloff rate at 20 minutes. A lower flow rate will form a less dense bed and decrease the pressure drop through any bed that has formed. Therefore, maintaining a constant, high flow in the tests results in a conservatively high head loss.

3. The PWROG FA test program defined a [ ]a,c Testing demonstrated that the maximum [ ]a,c

These conservatisms are further discussed in [5] and quantified by the Margin Calculator.

1.3.2.3 Hot-Leg Break

The original hot-leg break data set contained limited information about [ ]a,c. Most of the tests were run with [ ]a,c. The few tests that were run with [ ]a,c

1.3.2.3.1 Additional Hot-Leg Break Test Data

The final fuel assembly pressure drop as a function of p:f ratio for all tests with [ ]a,c. As previously discussed, the entire hot-leg break data set is shown on Figure 1-5. [ ]a,c

1.3.2.3.2 Hot-Leg Break Conservatism

The conservatism in the acceptance criterion for hot-leg breaks includes the following:

1. A [ ]a,c was chosen for testing that represents an upper bound for all plants. The plant-specific [ ]a,c.

2. The PWROG fuel assembly test program defined a [ ]a,c This relationship does not account for the amount of fiber that will be caught on the sump strainer during multiple passes. The maximum debris load is conservative as the full load is not expected to accumulate in the fuel. Therefore, the dP_{debris} will be less than that predicted by the PWROG relationship.

3. Limiting results were observed for blockage at a single spacer grid near the core inlet. It is unlikely that this will occur in all of the fuel assemblies in a core because of the complex and multi-dimensional flow patterns in the reactor vessel lower plenum. That is, the uniform, constant flow simulated in the test rig promotes debris capture at the first spacer grid. It is postulated that once debris begins to catch at the spacer grid in a full core, the flow will begin to divert to lower pressure regions of the core. This diverted flow may or may not carry debris to the immediately adjacent spacer grid, but may instead introduce debris further into the core.

4. Flow paths around a debris bed buildup ("alternate flowpaths") have not been considered or credited. Limiting results were observed for blockage at a single spacer grid near the core inlet. The limiting scenario would be for this to occur in every fuel assembly in the core. While this is not likely (see previous conservatism), if it occurs, then flow through alternate flow paths may be credited. Most plants have baffle regions that run parallel to the core region and connect the reactor vessel lower plenum and the reactor vessel upper plenum. If this geometry exists (referred to as "upflow baffle configuration"), this path should be characterized as to the size of the openings to ensure that they won't block and the flow losses to determine the pressure drop required to drive sufficient flow to remove core decay heat and preclude the buildup of boric acid.

a,c

Table 1-4: [ ]

Table 1-5: [ ]

1.4 RAI #4

1.4.1 Question

In a number of tests (e.g., CIB03, CIB04, CIB09) with chemical precipitates in the debris mix, the graphs show that upon the addition of the first batch of chemical precipitate, a quick increase in pressure drop is observed, followed by a decrease in pressure drop with similar or no response to additional chemical precipitate additions. This observation is contrary to observations made during strainer head-loss testing. Please discuss why the addition of chemical precipitates did not result in a sustainable increase in pressure drop.

1.4.2 Response

[

]a,c

1.4.2.1 Debris Bed Formation

( )a,c

a,c

a,c

Table 1-6: [ ]

1.5 RAI #5

1.5.1 Question

During one of the fuel assembly tests for the AP1000 plant, there was a much greater increase in pressure drop upon adding chemical precipitate than has been observed in the WCAP-17057-P tests for the operating reactors. Please describe any discrepancies between the AP1000 and operating reactors test conditions and explain why a much greater increase in pressure drop from chemical precipitate is not observed in the operating reactor fuel assemblies.

1.5.2 Response

[

]a,c

1.6 RAI #6

1.6.1 Question

In paragraph 6.2.1, the Darcy-Weisbach equation is used to estimate the cold-leg break pressure drop at the core inlet from hot-leg break test results. However, the calculated pressure drop is not corroborated by the cold-leg test or by other tests observed by NRC staff. The staff believes that Darcy-Weisbach equation does not accurately model flow through a porous media. Please justify its use in this application.

1.6.2 Response

WCAP-17057-P only uses the Darcy-Weisbach equation as a tool to determine the order of magnitude to predict the expected cold-leg break dP if only hot-leg break dP results were available. Section 6.2.4 discusses the cold-leg results and recognizes that the actual results were higher than those calculated in Section 6.2.1.

1.7 RAI #7

1.7.1 Question

The Westinghouse tests did not include a test with microporous insulation without having calcium silicate insulation in the debris mix. Please provide an evaluation of how microporous insulation debris affects fuel assembly head loss without calcium silicate present or show that this condition is not applicable for operating reactors. Test CIB06 results indicate that calcium silicate may reduce head loss and it appears that the particulate component of microporous insulation debris may result in an increase in head loss. Unless it can be shown that microporous insulation will only be present when calcium silicate is present, please provide an evaluation of the effect of microporous insulation without cal-sil present. Please also provide an evaluation of how the microporous insulation can affect head loss under various flow and debris loading conditions to assure that the limiting amount of microporous insulation has been determined.

1.7.2 Response

Upon issuance of this RAI, the test results of the original Westinghouse and AREVA test programs were compared [2 & 3]. Additionally, the PWROG conducted additional fuel assembly tests at lower flow rates to fully evaluate the effects of Microtherm at varying flow conditions [4]. It was concluded microporous insulation behaves like a particulate and should be characterized as such. Therefore, plants with microporous insulation are bounded by the results of tests conducted with silicon carbide as the particulate source. This conclusion is supported by the discussions presented in Section 1.1.

1.8 RAI #8

1.8.1 Question

The data presented in Table 5-1 and Figures 5-1, 5-2, and 5-3, suggests that debris behaves differently in tests at lower flows, (e.g., cold leg testing and CE testing) than in tests at high flow rates (e.g., hot leg testing). Based on high flow rate test results, the tests at low flow rates incurred higher than expected head losses across the bottom nozzle. Further, the lower-flow tests did not include potentially problematic debris types like microporous insulation, nor were the tests conducted with a full range of debris loads. Please provide information to justify that a sufficient range of conditions was evaluated for the cold leg break and other low-flow testing, including information that adequate debris types and load combinations were considered such that the head losses greater than the acceptance criteria will not occur.

1.8.2 Response

As discussed in the previous sections, additional testing was conducted to evaluate the full range of debris loads. A summary of the additional testing is provided in Table 1-7. This testing, in combination with the data provided in [2 & 3], was used to update the debris load acceptance criteria as defined in Section 1.2.

a,c

Table 1-7: [ ]

2.0 References

1. "Request for Additional Information RE: Pressurized Water Reactor Owners Group Topical Report WCAP-16793-NP, Revision 1, 'Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid' (TAC No. ME1234)," January 8, 2010. (ADAMS Accession Number: ML093490855.)
2. WCAP-17057-P, Revision 0, "GSI-191 Fuel Assembly Test Report for PWROG," March 2009.
3. 51-9102685-000, "GSI-191 FA Test Report for PWROG," March 2009.
4. STD-MCE-10-12, "Summary of Results from PWROG Core Inlet Blockage Tests: CIB21 through CIB40," January 2010.
5. [ ]a,c